Evaluation of Phase Change Materials for the Reduction of Temperature Swing in Composite Climate

A Synopsis Submitted to

Shri Vaishnav Vidyapeeth Vishwavidyalaya

For

DOCTOR OF PHILOSOPHY

IN

MECHANICAL ENGINEERING

By

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TABLE OF CONTENTS

1.	**Introduction**	1
	Overview of Pollution from Buildings	1
2.	**Review of Literature**	4
	2.1 Scenario of Research in the Proposed Field	4
	2.2 Research Contributions in the Proposed Field	5
	2.3Rationale	17
	2.4Gaps in the Research	18
3.	**Objectives of Research**	19
4.	**Proposed Solution Methodology**	20
5.	**Research Schedule**	22
6.	**References& Web Resources**	23

LIST OF TABLES

Table No.	Title	Page No.
Table 2.1	Contributions of Researchers in the Proposed Field	5
Table 5.1	Schedule of Research Work	22

LIST OF FIGURES

Figure No.	Title	Page No.
Figure 2.1	Radar graph showing Reduction in temperature swings in buildings	4
Figure 4.1	Proposed Solution Methodology	22

LIST OF ABBREVIATIONS

Abbreviation	Full Form
HVAC	Heating, Ventilation and Air Conditioning
PCM	Phase Change Material

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1
Introduction

Overview of Pollution from Buildings

Globalizations, economic progress, and growing living standards, say Gupta et al. (2023), have placed a heavy stress on fossil based energy to provide the increased demand for power. The population boom has made the already dire situation much worse. Furthermore, excessive fossil fuel extraction contributes significantly to environmental degradation in the form of global warming and climate change. The significant increase in global energy use, Sinha et al. (2022) noted, has prompted worries about things like ozone depletion and climate change. About 40 percent of the energy used in the world is for enclosed spaces like homes and businesses, and that number is rising steadily owing to factors like population growth, urbanisation, and economic development. Strategic actions to create energy efficient technology are required to meet the energy needs of the construction industry. Urbanisation and improvements in people's level of life have resulted in a worldwide spike in the demand for energy. The construction industry is one of the biggest energy consumers, accounting for around 40% of total energy use. The heating and cooling systems in a structure use the bulk of the energy needed to maintain a comfortable interior temperature. Researchers have a fundamental difficulty, then, in lowering their carbon footprint while also improving their workplace's thermal comfort.

About 40 percent of all carbon dioxide emissions, both direct and indirect, come from the construction industry, as reported by Kenzhekhanov et al. (2020). Forecasts suggest that, owing to increased living standards, global energy consumption may continue to rise. Heating and cooling requirements account for a significant percentage of a building's total energy use. As a consequence, cutting down on energy use and, therefore, CO_2 emissions, may be aided by the creation of energy-efficient buildings. According to Nurlybevkova et al. (2021), buildings account for 40% of global CO_2 emissions due to their high energy use. The majority of this power is used for HVAC purposes. Therefore, it is essential to create energy-efficient structures in order to reduce the amount of energy used by the building industry and, by extension, CO_2 emissions.

Additional guidance is provided by Sinha et al. (2022), who state that increasing atmospheric CO2 concentrations threaten climatic stability. More than 30 percent of all CO2 emissions occur in closed contexts, such as the construction industry. In most industrialised nations, the construction industry consumes more energy than the manufacturing and transportation industries put together.

It is becoming clearer that energy-efficient and sustainable buildings are necessary due to shifting lifestyles, the state of the economy, and the state of the environment, as stated by Kumar et al. (2023). Energy-efficient building envelopes have been developed using a number of different technologies throughout the years. The potential for energy saving and thermal comfort in buildings is one reason why the use of phase change materials (PCMs) has gained popularity in recent years, as noted by Li et al. (2020). Raheim et al. (2023) classify PCMs into three groups based on the molecules they contain: organic compounds, inorganic compounds, and eutectic mixes of the two. In the field of thermal energy storage, organic compounds are often employed as phase change material (PCM). There are two main types: paraffin and non-paraffin. Fatty acids, glycols, and aster are only few of the many organic compounds found in the non-paraffin. Using PCM correctly in a building may drastically cut down on the amount of energy needed to maintain an acceptable temperature inside. The use of PCM into building envelopes has the potential to increase thermal comfort within the structure while decreasing energy use.

The suggested study takes these considerations into account via a comparative investigation of several phase change materials with the aim of mitigating temperature fluctuations in composite environments. Natural and synthetic materials will be put through their paces in climate-controlled environments to determine which one works best for the intended structure.

2

Review of Literature

The present chapter highlights the scenario of research in the proposed field, contributions of different researchers in the proposed field as well as gaps in the research, the details of which are presented in upcoming sub-sections.

2.1 Scenario of Research in the Proposed Field

Figure 2.1 presents the showing the number of research papers published in the last five years for the search terms *reduction in temperature swings in buildings*, prepared from the information of available at www.scholar.google.com.

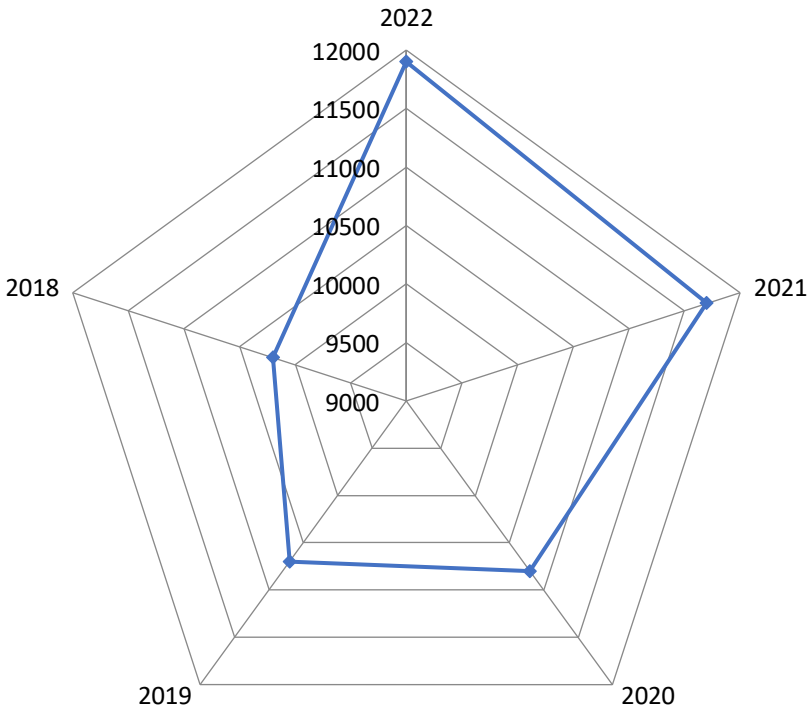

Figure 2.1:Radar graph showing Reduction in temperature swings in buildings

(www.scholar.google.com)

Based on the information provided by Figure 2.1, one can easily understand the scenario of research in the proposed field.

2.2 Research contributions in the Proposed Field

Table 2.1 represents some of the selected research contributions in the field of deduction in temperature swing in composite climate.

Table 2.1: Contributions of Researchers in the Proposed Field

S. No	Author(s) (Year)	Name of Journal / Publisher	Title	Objective	Findings	Limitations /Gaps
1.	Hamdan et al. (2023)	International Journal of Energy for a Clean Environment	Energy Management in Buildings Using Bio Phase Change Material	The research work investigates the use of phase change material in buildings or improving passive energy conservation	Finding of the research work showed the maximum temperature variation of 4 degrees and temperature swing of 6.5 degrees, and heating loads were found to be 3.49 percent	The research work neglected different categories of phase change materials
2.	Sepehri&Pavlak (2023)	Energy and Buildings	Evaluating optimal control of active insulation and HVAC systems in residential buildings	To find the optimal parameter for reducing active insulation and HVAC systems	The researchers investigated the possible yearly savings by combining AIS and HVAC systems in United States	The research work neglects the involvement of phase change materials
3.	Raheim et	Energy	The essential	To select	Investigations	Secondary

	al. (2023)		properties governing the appropriate selection of phase change materials integrated into heavy structure buildings	proper phase change materials for a given building application	on thermal properties of nine phase change materials	data was used in the research work, which has its own limitations
4.	Gupta et al. (2023)	Journal of Energy Storage	Experimental analysis of clay bricks incorporated with phase change material for enhanced thermal energy storage in buildings	To analyse the influence of macroscapsules of varying shapes, on the thermal performance of clay bricks	As the result of research work, the cooling load was found to be reduced by 23.66 percentage, and 3.31percentage with different combination of bricks	Only two materials were used in the research work
5.	Kumar et al.(2023)	Applied Thermal Engineering	Integration of lauric acid/zeolite/graphite as shape stabilized composite phase change material in gypsum for enhanced	Analysis of Gypsum plaster loaded with Shaped stabilized composite PCM for temperature control	Positive results obtained as the result of the research work	Comparison of different materials was not provided

			thermal energy storage in buildings			
6.	Sinha et al. (2022)	Applied Energy	Reduced building energy consumption by combined indoor CO2 and H2O composition control	To analyze a ventilation system which controls the indoor air quality, needs less air conditioning and manages both the carbon dioxide and water	The designed ventilation system was found to be 55 percent more cost effective and needed 35 percent less energy	Only one type of ventilation system was targeted
7.	Alayed et al. (2022)	Energy and Buildings	Thermal mass impact on energy consumption for buildings in hot climates: A novel finite element modelling study comparing building	To quantify the mass effect on a building	The results of the research work showed that the energy consumption of a building is higher when a part of its thermal substantial wall is exposed to the inside	Absence of phase change materials

			constructions for arid climates in Saudi Arabia			
8.	Gopalan et al. (2022)	Energy Reports	Performance enhancement of building energy through the combination of dynamic insulation panels and phase changing materials	To investigate the importance of insulating layers at different scales in buildings	Considerable positive results were obtained as the results of this study	Particular parts of buildings were considered
9.	Suresh et al. (2022)	Energy and Buildings	Phase change material incorporation techniques in building envelopes for enhancing the building thermal Comfort-A review.	To analyze the effect of phase change materials at different locations of the building	Results of the research work showed that PCMs with phase change transition temperatures near ambient contributes to thermal comfort for the buildings	Comparison of phase change materials was missed
10.	Shah et al. (2022)	Energy and Buildings	Application of phase change materials in building components	To analyse different aspects of the passive.ly cooled	Suitability of PCMs was found as the result of research work	The research work neglects the effects of PCMs on

			and the use of nanotechnology for its improvement	materials, on the basis of their use in different building components		the whole buildings
11.	Gonclaves et al. (2021)	Building and Environment	PCM-containing bi-layered alkali-activated materials: A novel and sustainable route to regulate the temperature and humidity fluctuations inside buildings	To investigate the suitability of alkali-activated composite with a thick bottom layer having different quantities of phase change materials	It was found that both mechanical and thermal performances are controlled by PCM content	The research neglects the comparison of different PCMs
12.	Paranjothi et al. (2021)	Energy and Buildings	Evaluation of phase change plaster/paste composites for building envelopes	Investigations on thermals energy storage over conventional heating and cooling systems	A methodology for calculating the levelized cost of storage for thermal energy storage was recommended	The research work neglects the financial analysis of the proposed system
13.	Mahadoui et al. (2021)	Construction and Building	Building bricks with phase change	To enhance the thermal efficiency	The results showed the reduction in	The research only

		Materials	material (PCM): Thermal performances	of outside walls by applying a PCM in hollow bricks	interior temperature fluctuations	considers a particular type of building element
14.	Nurlybevkova et al. (2021)	Energy	Quantitative evaluation of the thermal and energy performance of the PCM integrated building in the subtropical climate zone for current and future climate scenario	To investigate the effect of PCM on thermal and energy performance of different buildings located in six cities	The findings of the research work showed the suitability of PCMs for different buildings	A particular number of cities were considered
15.	Gandhi et al. (2020)	Sustainability	A review on shape-stabilized phase change materials for latent energy storage in buildings	To evaluate the performance of shape-stabilized material	The research advocates the use of novel materials for the purpose.	Limited number of building elements were used during the research work
16.	Arivazhagan et al. (2020)	Materials Today: Proceedings	Review on performance assessment of phase change	To provide a review of integration of PCM in	As the results of the research work, different advantages of	A case study showing the use of

			materials in buildings for thermal management through passive approach	buildings	the targeted materials were highlighted	materials was missed
17.	Kenzhekhanov et al. (2020)	Energy	Quantitative evaluation of thermal performance and energy saving potential of the building integrated with PCM in a subarctic climate	To evaluate the thermal performance of 9 PCMs	Comparison of different alternatives was found out	Along with the materials, building parts could be evaluated, which was found to be missed during the research work
18.	Li et al. (2020)	Journal of Building Engineering	Experimental thermal performance of wallboard with hybrid microencapsulated phase change materials for building application	Analysis of wallboard with hybrid PCMs for building applications	Results advocating the use of PCMs were obtained	The research was focussed on limited building parts
19.	Ahangari and	Sustainable Cities	An innovative	To reduce the energy	The findings shown that the	Only two types of

	Maerefat (2019)	and Society	PCM system for thermal comfort improvement and energy demand reduction in building under different climate conditions	consumption and enhance thermal comfort by providing a novel double-layer PCM system	percentage of time that interior thermal comfort criteria are satisfied is increased from 73% to 93% when using a double layer PCM system in a dry region, and from 63% to 75% when using the system in a semi-arid climate during the winter. Energy savings for heating in Iran range from 10.4% in semi-arid regions to 17.5% in dry regions.	alternatives were considered during the research work, which might be enhanced
20.	Gounni et al. (2019)	Applied Thermal Engineering	Thermal and economic evaluation of new insulation materials for building envelope based on	how well the newly created insulating materials function when applied to an outside	The proposed materials showed positive results	Limited number of materials were worked out

			textile waste	building wall in Casablanca, Morocco's actual climate		
21.	Xing et al. (2019)	Energy and Buildings	Experimental investigation on the thermal performance of a vertical greening system with green roof in wet and cold climates during winter	To analyse the effect of vertical greening system on indoor climate and energy consumption in both cold and wet climatic conditions during different conditions	The results of the research work showed the positive results obtained by using vertical greening system	The research work neglected the impact of different colors
22.	Sun et al. (2019)	Energy	Use of encapsulated phase change materials in lightweight building walls for annual thermal regulation	To analyse the impact of PCMs on different wall samples in different weathers	A mathematical model with the simulation results were obtained as the result of research work	Only walls were considered for the purpose of study
23.	Monna et	IOP	Improving	To analyse	Positive results	Comparison

	al. (2019)	Publishing	thermal environment for school buildings in Palestine, the role of passive design	the effect of passive environment control system	were obtained with pilot school	of different materials was not provided
24.	Singh &Bhat (2018)	Energy and Buildings	Performance evaluation of dual phase change material gypsum board for the reduction of temperature swings in a building prototype in composite climate	To compare the thermal performance of dual phase change material gypsum board with the conventional one.	Results advocating the dual phase change material gypsum board were obtained	Only one material was used during the research work
25.	Berardi and Soudian2018)	Building simulation, Tsinghua University Press	Benefits of latent thermal energy storage in the retrofit of Canadian high-rise residential buildings	To investigate the benefits of passive latent thermal energy storage systems by using PCMs in ceilings	Results advocating the use of PCMs were obtained	Post implementation analysis was not provided

26.	Li et al. (2018)	Sustainability	Numerical thermal characterization and performance metrics of building envelopes containing phase change materials for energy-efficient buildings	To investigate the energy efficiency using PCM layers	Findings of the research work advocated the PCM-enabled building walls showed a great improvement in its thermal performance,	Financial analysis was missed
27.	Zhu et al. (2018)	Sustainable cities and society	A review on applications of shape-stabilized phase change materials embedded in building enclosure in recent ten years	To review the applications of Shape-stabilized phase change materials in last ten years	It was found that Shape-stabilized phase change materials can decrease the indoor temperatures and energy demands considerably	Implementation aspects of the research were absent
28.	Kaeian et al. (2017)	Energy and Buildings	Experimental studies on the applications of PCMs and nano-PCMs in buildings: A critical	To summarize experimental studies on the applications of nano-PCM and	Based on the applications, the gaps as well as objectives of the research were investigated	Practical aspects was found to be missed during the research work

			review	PCM building		
29.	Guarino et al. (2017)	Applied Energy	PCM thermal storage design in buildings: Experimental studies and applications to solaria in cold climates	To analyze the performance of a building integrated thermal storage	Findings of the research work advocate that the proposed system may be suitable for all year round conditions	The research work was conducted in a particular country, Cadada, only.
30.	Berardi et al. (2017)	Energy and Buildings	Water-to-air-heat exchanger and indirect evaporative cooling in buildings with green roofs	To analyze the effect of water-to-air-heat exchanger and indirect evaporative cooling in green roof based buildings	Satisfactory results were obtained from the research work	Limited number of approaches were used during the research work
31.	Soudian and Berardi (1017)	Energy Procedia	Experimental investigation of latent thermal energy storage in high-rise residential buildings in	To analyse the performance of different PCMs with different melting points.	Significant temperature drop in daily temperature fluctuations	Only two systems were analysed

			Toronto			
32.	Kim et al. (2017)	Building and Environment	Application of shape-stabilized phase-change material sheets as thermal energy storage to reduce heating load in Japanese climate	To analyse the performance of shape stabilized phase change material sheet as thermal energy storage	Findings of the research work show that heat storage performance depends on the installation area and position of the sheets	The research work was carried out only in a particular country (Japan)

2.3 Rationale

World population has reached to 8 billion in 2023. This is associated with overall growth in industrial, agriculture, transport and infrastructure sectors. Among all, industrial and residential building sectors are contributing significantly to the rise in electric energy demands, the rise in urbanization has increased energy consumption in residential and commercial buildings. Among the total energy consumption in buildings, about 45% of energy is consumed in maintaining the indoor thermal comfort conditions. Further greenhouse gas emission associated with buildings in India has increased considerably and it is projected that it could reach 700% in 2050 compared to emission level in 2005 if the same energy consumption pattern is continued. In order to curb this rising energy demand, many researchers and scientists are focusing on the design of energy-efficient buildings. Energy-efficient buildings aim at achieving a sustainable environment which response to climatic conditions using passive design changes and low energy systems. Passive cooling is an effective passive design strategy with a growing interest in saving energy and environment

protection. This is, however, not always a feasible option. It potentially primarily depends on the climatic conditions. Thus, an understanding of the building environment along with its climatic condition is essential for designers to adopt suitable passive cooling strategies in the building..

Proposed research focuses on:-

a) How much temperature swing can be reduced by using Phase change materials.
b) How much energy we can save by using Phase Change Material.
c) Experimental analysis of effectiveness of the materials on the basis of temperature reduction in composite climate along with the validation of results using simulation approach in different climate.
d) What will be the cost incurred for different alternatives.
e) What will be the impact of this research on environment and sustainability?
f) How the material is suitable according to composite climate.

2.3 Gaps in the Research and Research Questions

Following points represent the gaps in the research:

a) There are very less research paper were found in literature which focuses on comparison of different phase change materials;
b) Few research papers were found, which focused on the ranking of phase change materials;
c) There were also very few research papers, found in the literature, which focused on experimental analysis on the research problem;
d) It was also found that a very few research papers considered all aspect of research like environmental, financial and thermal comfort; and
e) Very few research papers focused on the analysis of phase change materials in different seasons.

On the basis of gaps in the research, the following research questions were appeared?

a) Is it possible to compare different phase change materials? If yes, then how?
b) If yes, then, what shall be the ranking procedure for the materials?
c) For the purpose of analysis, which timings and approaches shall be considered?

3

Objectives of the Research

Following points represent the objectives of the proposed research work:

a) To investigate different types of natural and synthetic insulating materials.

b) To identify the effectiveness of different natural and synthetic insulating materials.

c) To construct and evaluate the temperature profile for different phase change material in composite climate.

d) To identify the stability and financial analysis of different phase change material.

e) To conduct comparative study of different PCM and rank them on basis of their effectiveness.

4

Proposed Solution Methodology

Figure 4.1 represents the proposed solution methodology for the research work:

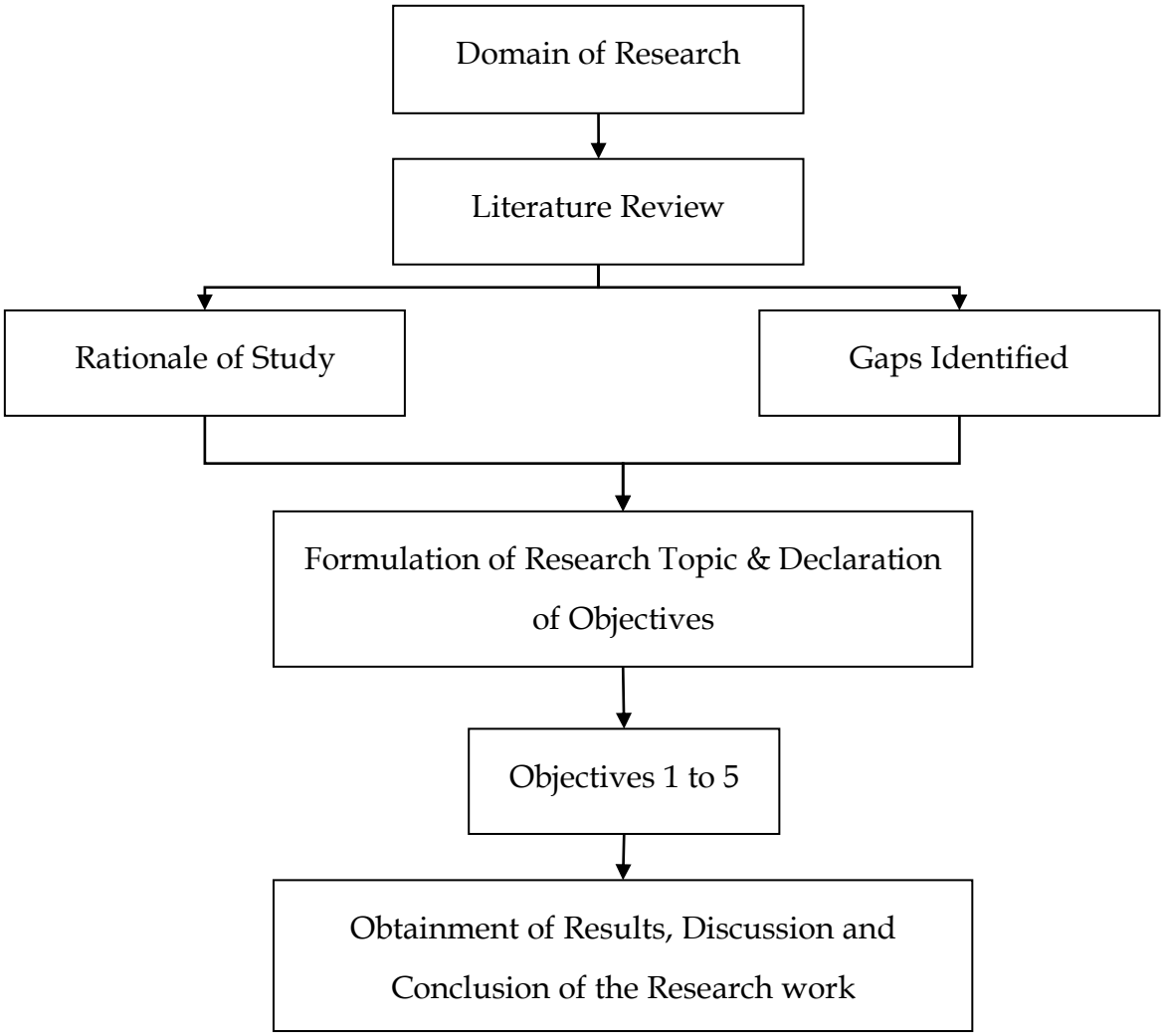
Domain of Research
Literature Review
Rationale of Study
Gaps Identified
Formulation of Research Topic & Declaration of Objectives
Objectives 1 to 5
Obtainment of Results, Discussion and Conclusion of the Research work

Figure 4.1: Research Flow Diagram

Details of different steps involved in the proposed solution methodology are presented as follows:

Step 1: First of all, in the domain of interest, gaps of research shall be investigated, and on this basis title of the research work, objectives of the research as well as rationale shall be determined (completed);

Step 2: In the next step, with the help of industry and academia, a list of competent heat resisting materials (like coconut joot slab , PCM fiber sheet , sub zero eutectic PCM's ,

Positive temperature Organic PCM's ect.) shall be investigated, for the purpose of selection of most suitable alternatives for the research work. The targeted alternative categories are natural and synthetic materials;

Step 3: In the next step, these materials' slabs shall be applied to the demo rooms for stipulated times in different seasons, for the purpose of recording the temperature variations. For this purpose standard room dimensions 1 m × 1 m × 1 m shall be selected. Figure 4.2 shows the schematics of the rooms.

Figure 4.2: Schematics rooms arrangements (Singh and Bhat, 2018)

(Picture shown for demo purpose only)

In given rooms, different natural as well as phase change materials shall be applied for the purpose of analysis.

Step 4: In this step from data logger we record all necessary data like Relative Humidity, Absolute Humidity , Wind Speed , Inner temperature of demo rooms , inner surface temperature of slabs , exterior surface temperature of demo rooms , atmospheric temperature , temperature swing.

Step 5: From the recorded data, temperature profiles for different materials in different seasons shall be created, which shall lead to further analyses procedures for the investigations for best alternatives. Further, with the available information, stability and financial analysis of alternatives shall also be conducted.

Simulation part shell also be done in this step for which according to the condition any simulation analysis software (Ansys , Matlab , ANN etc)can be chosen.

Step 6: In the next step of the research, on the basis of results obtained from different analyses, rankings of different alternatives shall be investigated, along with their effectiveness;

Step 7: Declaration of results and conclusion of the research work.

Chapter V
Research Schedule

Table 5.1 shows the schedule for the research work, as follows:

Table 5.1: Schedule of Research Work

S. No	Year	Schedule of Research Work
1.	**Ist**	Course work and finalization of the research topic
2.		Review of literature and finalization of methodology
3.		Selection of alternatives
4.	**IInd**	Creation of demo rooms and application of alternatives' slabs
5.		Year round monitoring of the demo rooms and collection of data
6.		Obtainment of results, and conclusion of research work
7.	**IIIrd**	Thesis preparation
8.		Publication of research papers
9.		Plagiarism checking and thesis submission

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